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(54) LIGHT-EMITTING DEVICE

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H01L 33/50 (2010.01)
H01L 33/44 (2010.01)
H01L 25/075 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 33/502*** (2013.01); ***H01L 33/44*** (2013.01); *H01L 25/0753* (2013.01); *H01L 33/505* (2013.01)

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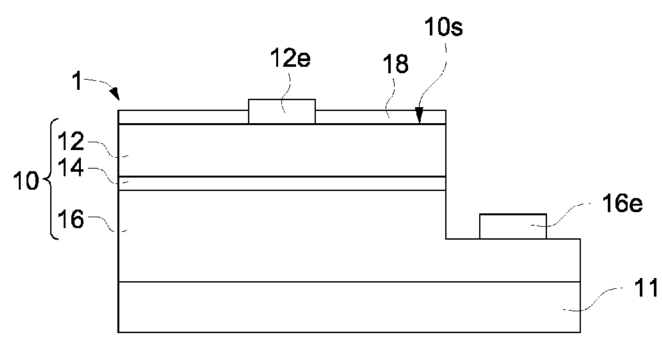
CPC H01L 33/502; H01L 51/5012; H01L 51/5036; H01L 2251/5384; H01L 27/3211; H01L 21/0259; H01L 2251/5346; H01L 2251/566; H01L 27/3206; G02F 1/1336; G02F 1/133603; G02F 1/133609; G02F 1/133611; G02F 1/1334; G02F 2203/01; G02F 1/133553; G02F 1/1347; G02F 1/133365; G02F 1/133524; G02F 1/133615; G02F 2201/086; G02F 2203/12; H05B 33/145; B29K 2995/0074; B82Y 30/00; C09K 19/544; H04N 9/3197; G09G 3/3648; G09G 2300/0434
USPC 257/13, 14, 40, 43, 714, 77, 79–103, 257/E21.172, E33.068, E21.09, E21.121, 257/E25.02, E33.008, E33.056, E33.063, 257/E33.073, E21.113, E29.068, E33.001, 257/E33.025, E33.06, E33.072, E21.002, 257/E21.006, E21.053, E21.077, E21.091, 257/E21.108, E21.126, E21.127, E21.138, 257/E21.17, E21.19, E21.229, E21.23, 257/E21.347, E21.352, E21.407, E21.411, 257/E21.414, E21.459, E21.475, E21.476, 257/E23.14, E27.121, E29.029, E29.089, 257/E29.09, E29.091, E29.249, E31.002, 257/E31.022, E31.102, E33.061; 438/22, 438/27, 29, 47, 46, 26, 478, 483, 535, 104, 438/24, 28, 33, 34, 35, 45, 479, 48, 480, 438/674, 681, 69, 778, 792, 796, 93, 967; 313/113, 498; 372/36, 50.11, 50.21, 372/96, 38.01, 43.01, 44.01, 45.01, 46.01, 372/75; 264/266, 261, 272.16
See application file for complete search history.



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(57) **ABSTRACT**

A light-emitting device of an embodiment of the present application comprises a substrate; a first semiconductor light-emitting structure formed on the substrate, wherein the first semiconductor light-emitting structure comprises a first semiconductor layer having a first conductivity type, a second semiconductor layer having a second conductivity type and a first active layer formed between the first semiconductor layer and the second semiconductor layer, wherein the first active layer is capable of emitting a first light having a first dominant wavelength; and a first thermal-sensitive layer formed on a path of the first light, wherein the first thermal-sensitive layer comprises a material characteristic which varies with a temperature change.

20 Claims, 14 Drawing Sheets

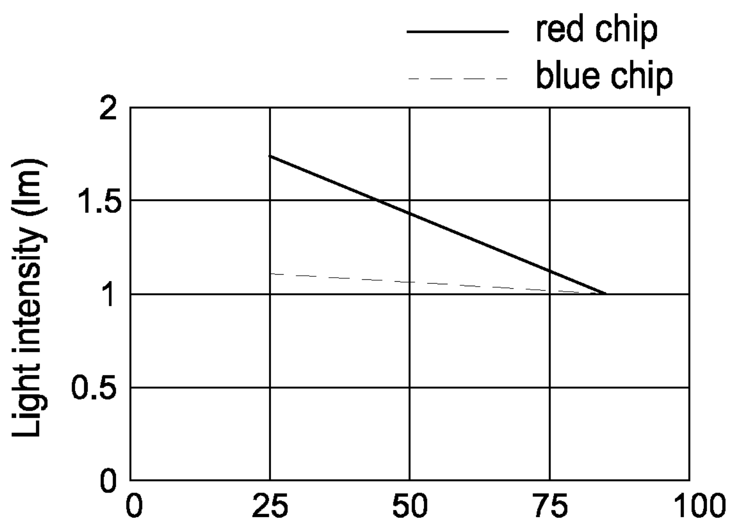


FIG.1 (PRIOR ART)

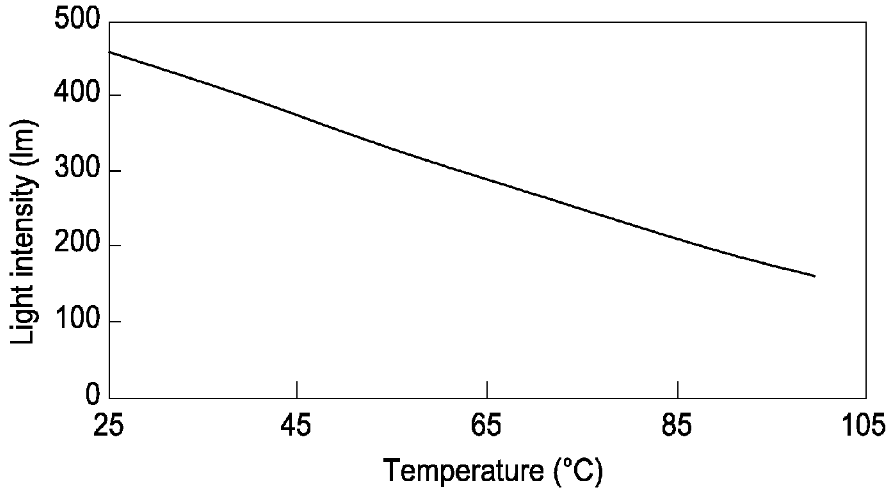


FIG.1A (PRIOR ART)

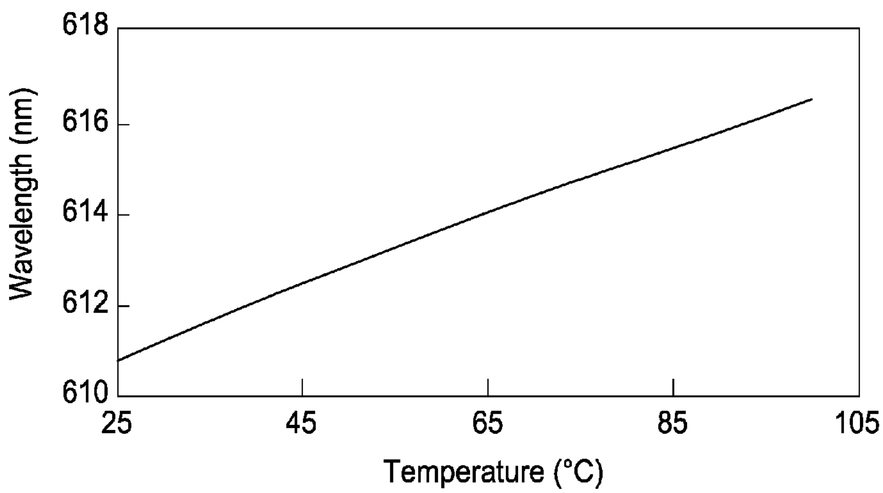


FIG.1B (PRIOR ART)

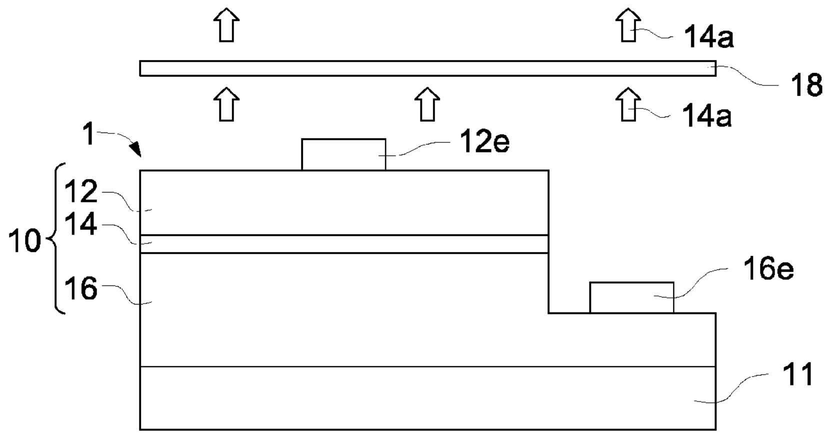

14a
18
14a
1
12e
12
14
10
16
16e
11

FIG.2

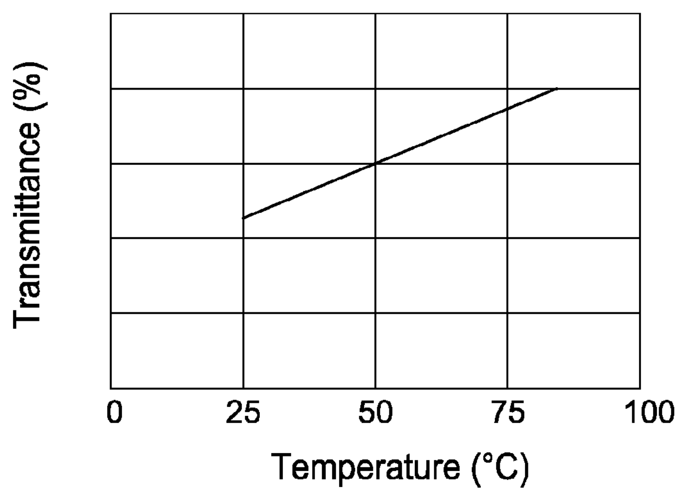

Transmittance (%)
0
25
50
75
100
Temperature (°C)

FIG.3

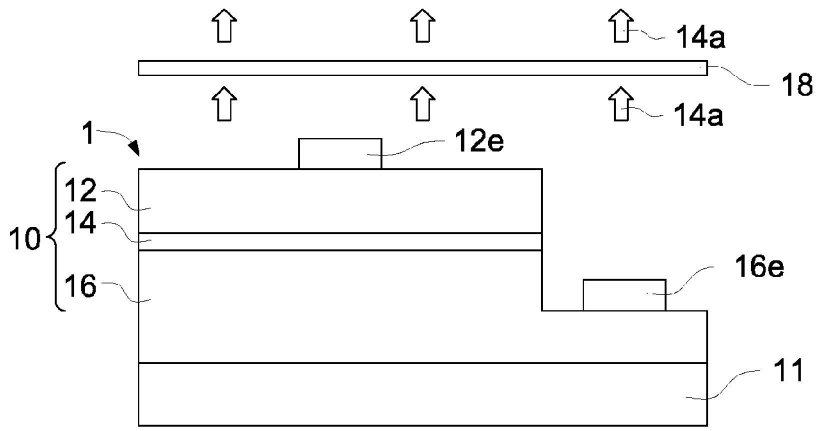


FIG.4

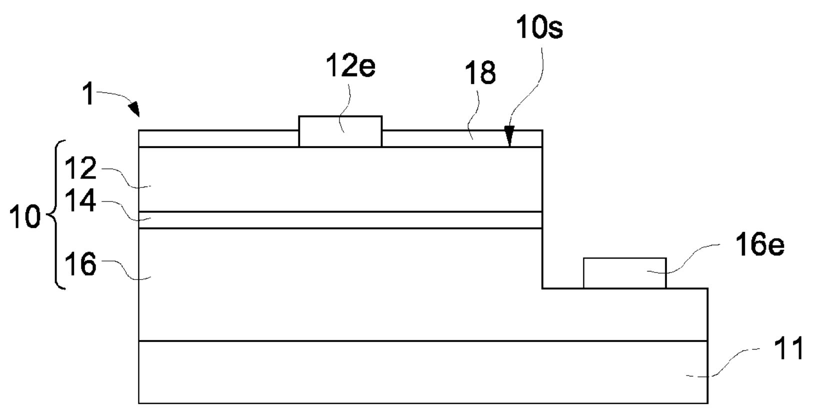


FIG.5

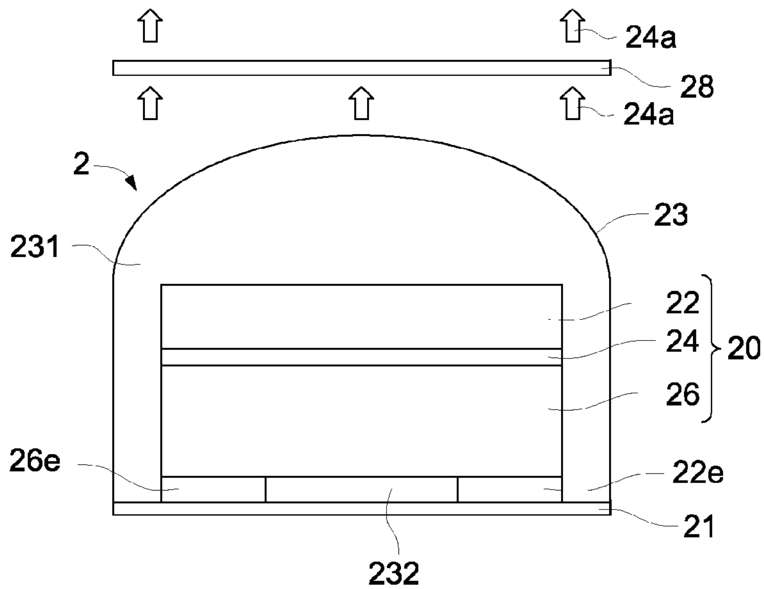

24a
28
24a
2
23
231
22
24
20
26
26e
22e
21
232

FIG.6

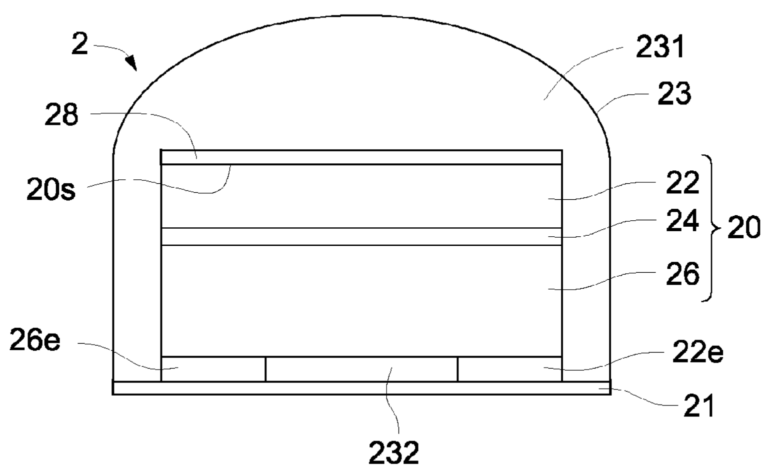

2
231
23
28
20s
22
24
20
26
26e
22e
21
232

FIG.7

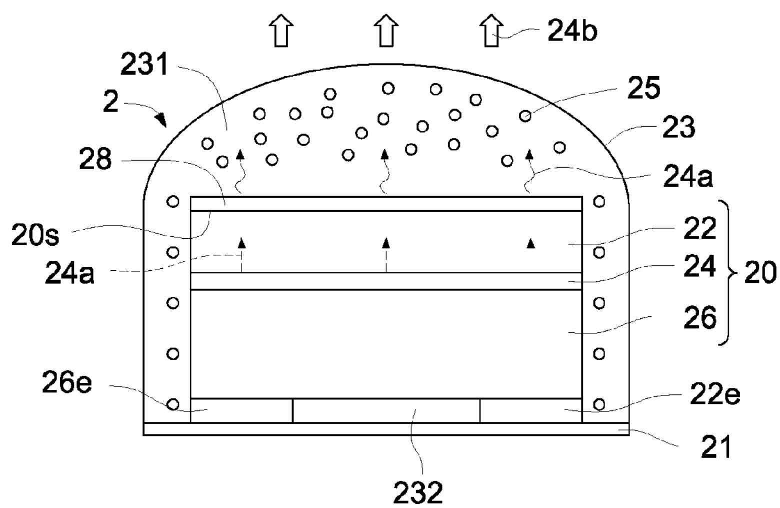

24b
231
25
2
23
28
24a
20s
22
24a
24
20
26
26e
22e
21
232

FIG.8

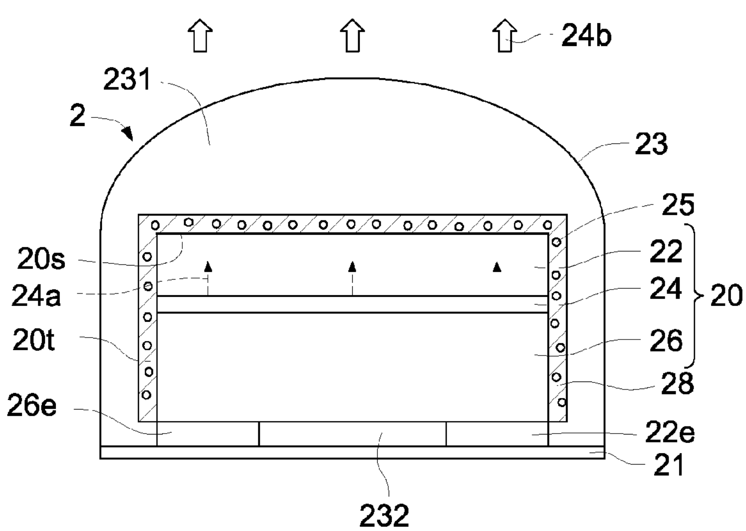

24b
231
2
23
25
20s
22
24a
24
20
20t
26
28
26e
22e
21
232

FIG.9

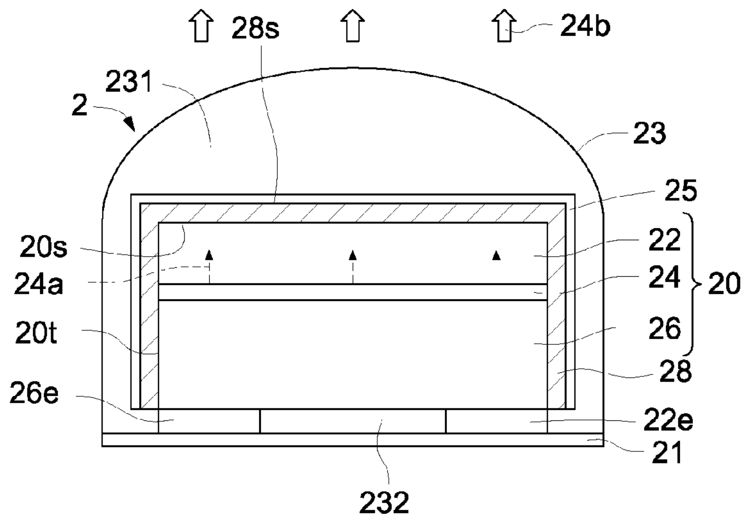
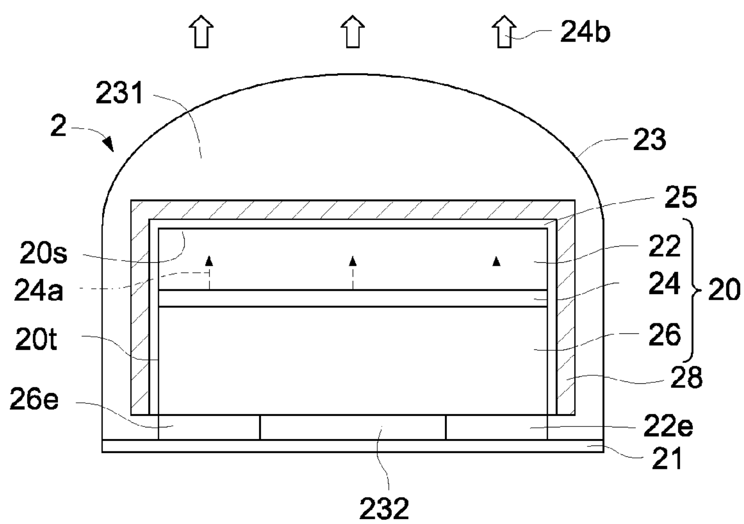

28s
24b
231
2
23
25
20s
22
24a
24
20
20t
26
28
26e
22e
21
232

FIG.10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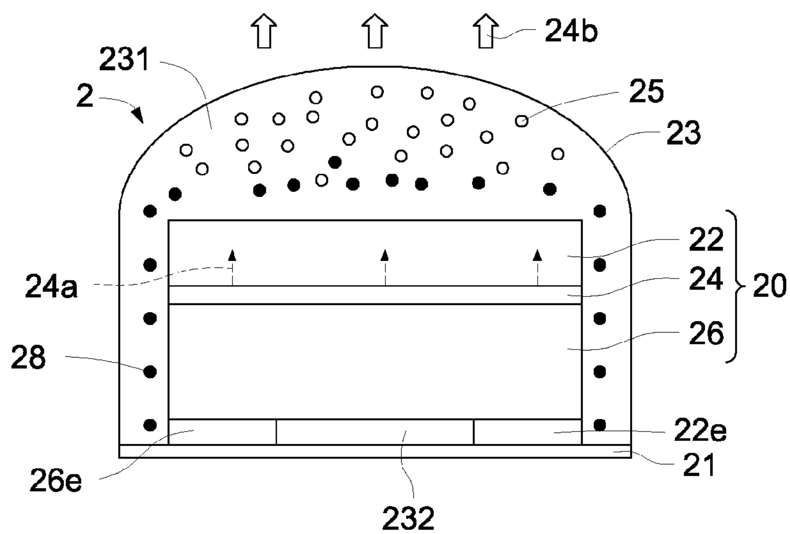
25
20s
22
24a
24
20
20t
26
28
26e
22e
21
232

FIG.11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231
2
25
23
22
24
20
24a
26
28
22e
21
26e
232

FIG.12

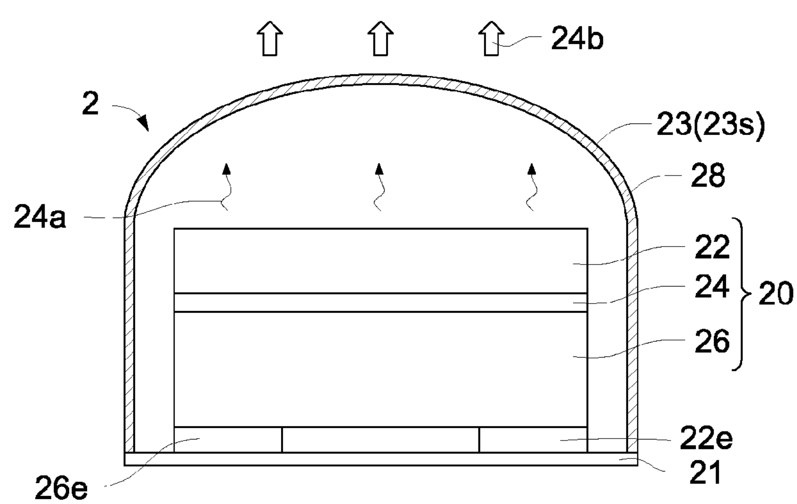

24b
2
23(23s)
28
24a
22
24
20
26
22e
21
26e

FIG.13

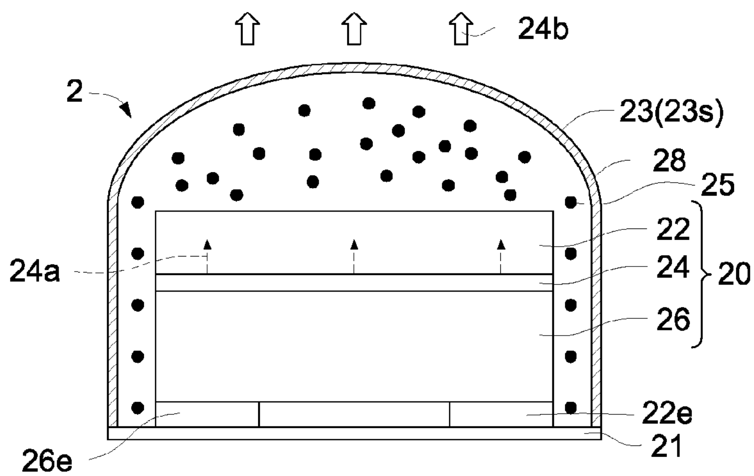
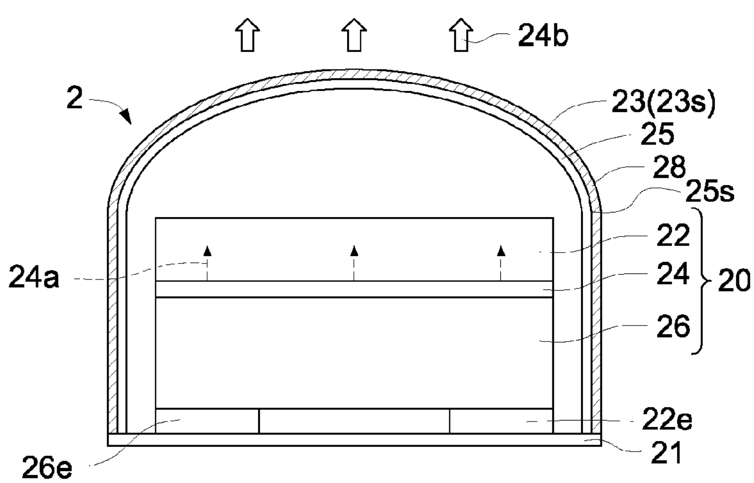

24b
2
23(23s)
28
25
22
24a
24
20
26
22e
21
26e

FIG.14


24b
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23(23s)
25
28
25s
22
24a
24
20
26
22e
21
26e

FIG.15

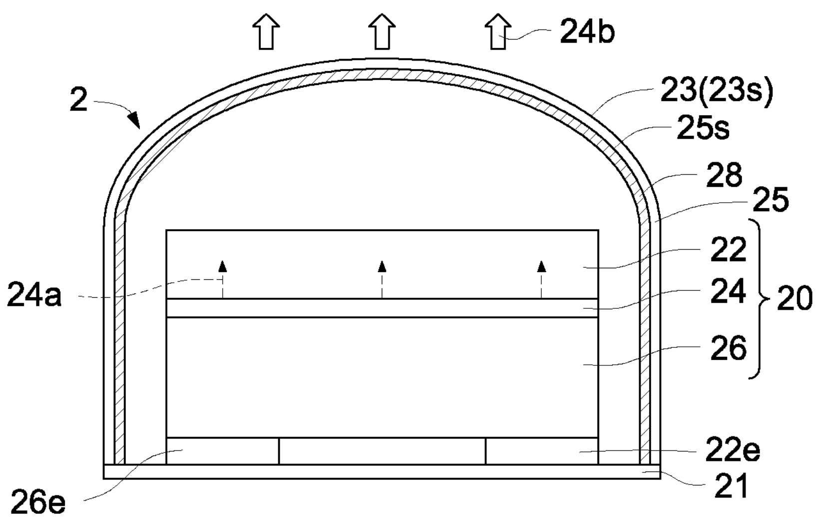
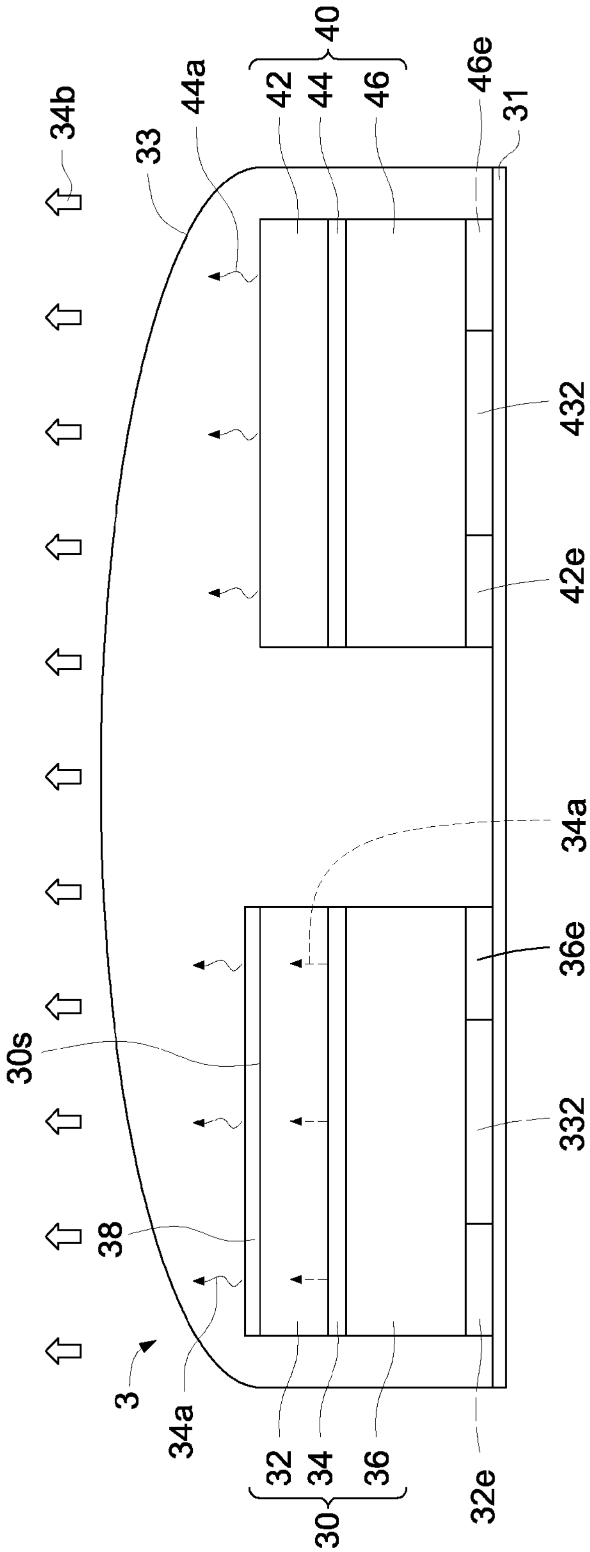


FIG.16



34b
33
44a
42
44
46
40
46e
31
432
42e
34a
36e
30s
332
38
3
34a
32
34
36
30
32e

FIG.17

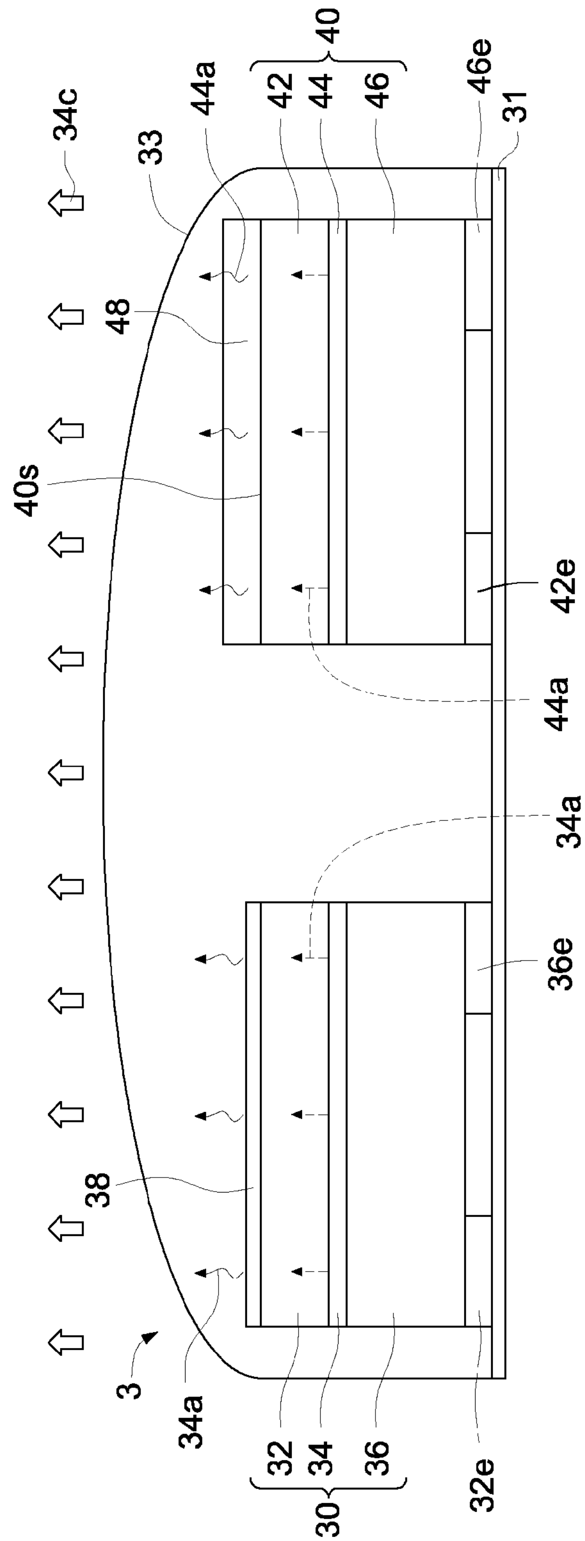
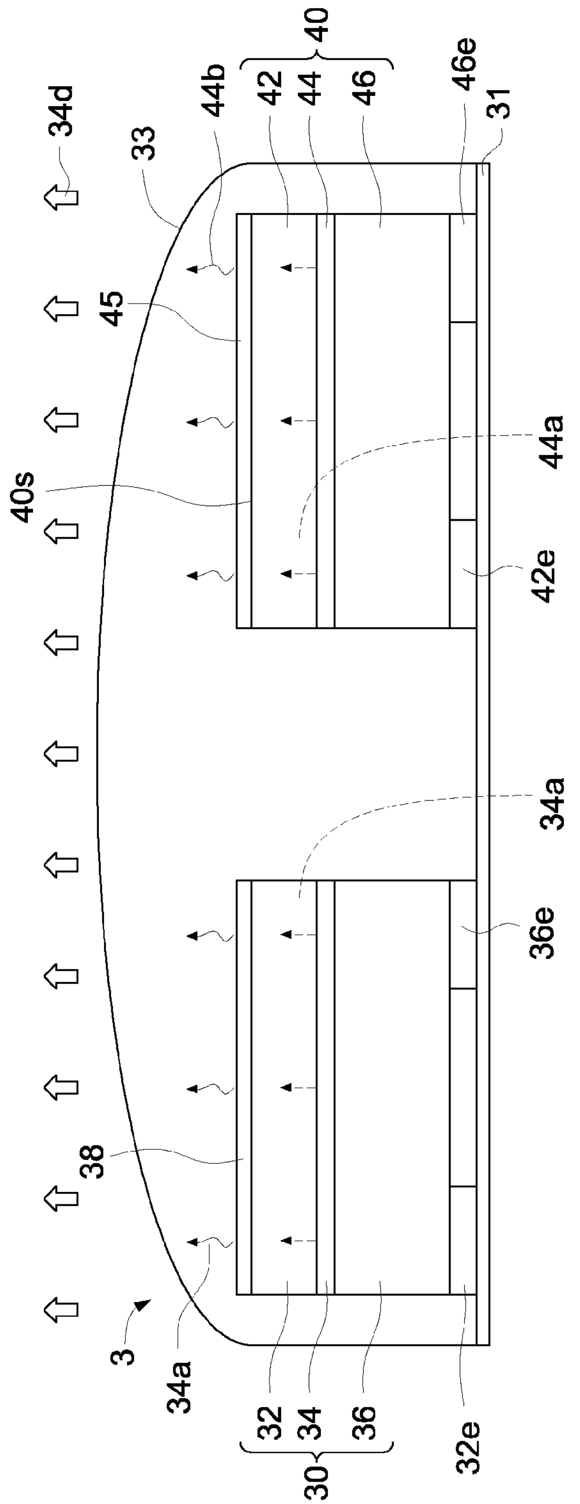

34c
33
44a
42
44
46
40
46e
31
48
40s
42e
44a
34a
36e
38
3
34a
32
34
36
30
32e

FIG.18


34d
33
44b
42
44
46
40
46e
31
45
40s
44a
42e
34a
36e
38
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34a
32
34
36
30
32e

FIG.19

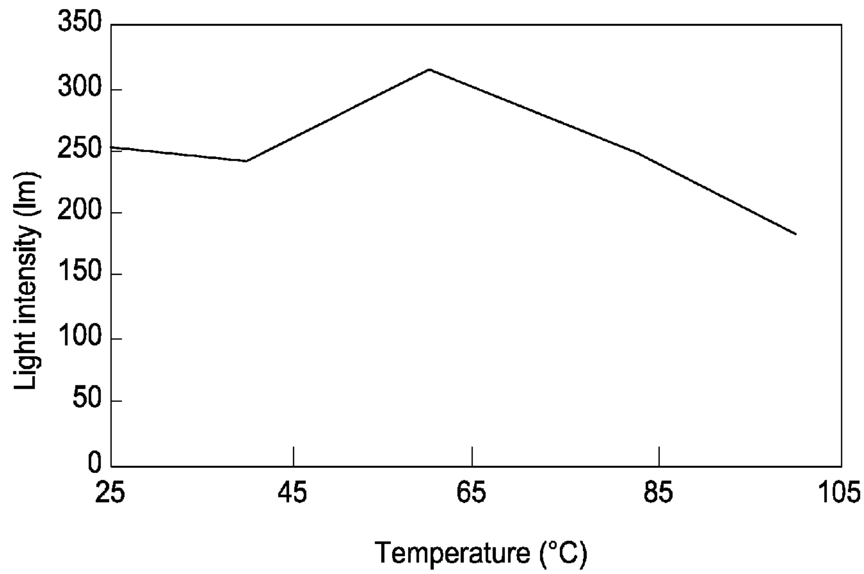
350
300
250
200
150
100
50
0
Light intensity (lm)
25
45
65
85
105
Temperature (°C)

FIG.20

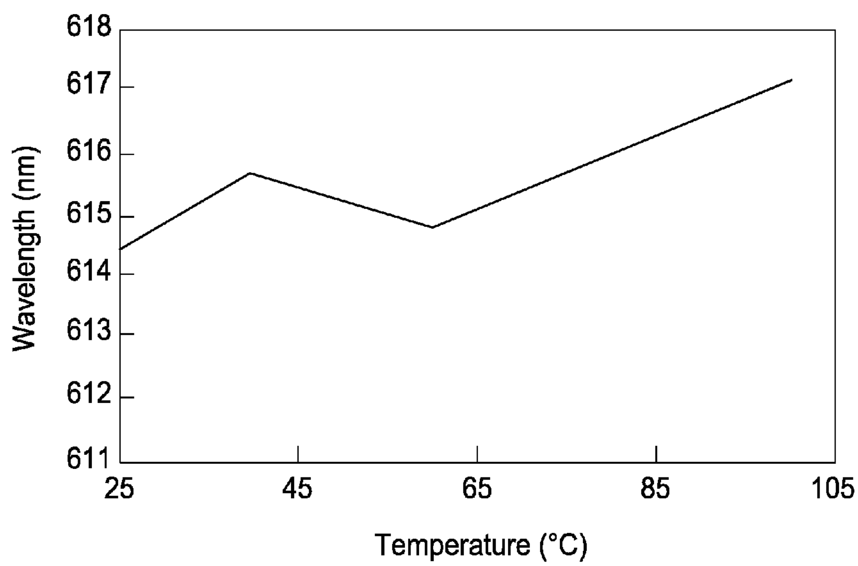
618
617
616
615
614
613
612
611
Wavelength (nm)
25
45
65
85
105
Temperature (°C)

FIG.21

LIGHT-EMITTING DEVICE

TECHNICAL FIELD

The application relates to a light-emitting device, and more particularly, to a light-emitting device having a thermal-sensitive layer.

REFERENCE TO RELATED APPLICATION

This application claims the right of priority based on TW application Ser. No. 101112423, filed on Apr. 6, 2012; TW application Ser. No. 101150407, filed on Dec. 26, 2012, and the contents of which are hereby incorporated by reference in their entireties.

DESCRIPTION OF BACKGROUND ART

The light-emitting diode (LED) is a solid state semiconductor device. A structure of the light-emitting diode (LED) comprises a p-type semiconductor layer, an n-type semiconductor layer, and an active layer. The active layer is formed between the p-type semiconductor layer and the n-type semiconductor layer. The structure of the LED generally comprises III-V group compound semiconductor such as gallium phosphide (GaP), gallium arsenide (GaAs), or gallium nitride (GaN). The light-emitting principle of the LED is the transformation of electrical energy to optical energy. An external electrical current drives electrons provided from the n-type semiconductor layer and holes provided from the p-type semiconductor layer to combine near p-n junction of the active layer. Then, the LED emits light when the electrons and the holes combine. However, during the combination of electrons and holes, part of electrical energy becomes heat which affects optical-electrical characteristics of the LED, for example, decreases light-emitting efficiency.

To achieve high color rendering and high efficiency of lighting requirements of the LED, a red chip capable of emitting a red light, a blue chip capable of emitting a blue light and a phosphor are usually combined to emit a white light. But, when the external electrical current is injected into the LED, part of electrical energy becomes heat. When the electrical current is continuously injected into the LED, thermal heat continues to accumulate. The accumulated thermal heat causes the temperature of the LED increasing and the light-emitting efficiency of the LED decreasing, while the thermal heat impacts the light-emitting efficiency of the red chip more than that of the blue chip.

As shown in FIG. **1**, when the external electrical current is injected into the LED, the temperature of the LED increases from an original temperature to a higher temperature, such as from 25° C. to 75° C. The photo decay dependence on temperature of the red chip is different from that of the blue chip, which leads to the color temperature of the LEDs at 25° C. being different from that of the LEDs at thermal equilibrium. The color temperature of the lighting apparatus therefore shifts and lighting apparatus can fail.

FIG. **1**A illustrates a diagram of light intensity dependence on temperature of a conventional red chip. As shown in FIG. **1**A, when the external electrical current is injected into the red chip, the temperature of the red chip increases from an original temperature to a higher temperature, such as from 25° C. to 85° C. or above, and the light intensity attenuates with increasing temperature. The attenuation rate of the light intensity versus temperature is approximately −0.87%/deg C. FIG. **1**B illustrates a diagram of emission wavelength dependence on temperature of a conventional red chip. As shown in

FIG. **1**B, when the external electrical current is injected into the red chip, the temperature of the red chip increases from an original temperature to a higher temperature, such as from 25° C. to 85° C. or above, and the emission wavelength shifts towards long wavelength with increasing temperature. When the temperature increases from 25° C. to 100° C., the emission wavelength of the red chip shifts about 5.7 nm.

Generally, electronically controlling method is used to solve the color temperature differences of the LED at thermal equilibrium state and at initial current driving state. However, this method increases the manufacturing cost of LED bulb.

SUMMARY OF THE APPLICATION

A light-emitting device of an embodiment of the present application comprises a substrate; a first semiconductor light-emitting structure formed on the substrate, wherein the first semiconductor light-emitting structure comprises a first semiconductor layer having a first conductivity type, a second semiconductor layer having a second conductivity type and a first active layer formed between the first semiconductor layer and the second semiconductor layer, wherein the first active layer is capable of emitting a first light having a first dominant wavelength; and a first thermal-sensitive layer formed on a path of the first light, wherein the first thermal-sensitive layer comprises a material characteristic which varies with a temperature change.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a diagram of light intensity dependence on temperature of a conventional red chip;

FIG. **1**A illustrates a diagram of light intensity dependence on temperature of a conventional red chip;

FIG. **1**B illustrates a diagram of emission wavelength dependence on temperature of a conventional red chip;

FIG. **2** illustrates a diagram of a light-emitting device in accordance with a first embodiment of the present application;

FIG. **3** illustrates a diagram of transmittance dependence on temperature of a thermal-sensitive material of the present application;

FIG. **4** illustrates a diagram of a light-emitting device in accordance with a first embodiment of the present application;

FIG. **5** illustrates a diagram of a light-emitting device in accordance with a first embodiment of the present application;

FIG. **6** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **7** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **8** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **9** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **10** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **11** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **12** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **13** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **14** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **15** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **16** illustrates a diagram of a light-emitting device in accordance with a second embodiment of the present application;

FIG. **17** illustrates a diagram of a light-emitting device in accordance with a third embodiment of the present application;

FIG. **18** illustrates a diagram of a light-emitting device in accordance with a third embodiment of the present application;

FIG. **19** illustrates a diagram of a light-emitting device in accordance with a third embodiment of the present application;

FIG. **20** illustrates a diagram of light intensity dependence on temperature of a light-emitting device of the present application; and

FIG. **21** illustrates a diagram of emission wavelength dependence on temperature of a light-emitting device of the present application.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The embodiment of the application is illustrated in detail, and is plotted in the drawings. The same or the similar part is illustrated in the drawings and the specification with the same number.

FIG. **2** illustrates a cross-sectional diagram of a light-emitting device **1** in accordance with a first embodiment of the present application. The light-emitting device **1** comprises a substrate **11**; a first semiconductor light-emitting structure **10** formed on the substrate **11**, wherein the first semiconductor light-emitting structure **10** comprises a first semiconductor layer **12** having a first conductivity type, a second semiconductor layer **16** having a second conductivity type, and a first active layer **14** formed between the first semiconductor layer **12** and the second semiconductor layer **16**, wherein the first active layer **14** is capable of emitting a first light **14***a* having a first dominant wavelength; and a first thermal-sensitive layer **18** formed on a path of the first light **14***a*, wherein the first thermal-sensitive layer **18** comprises a material characteristic which varies with the temperature change.

The material of the first semiconductor light-emitting structure **10** comprises an element selected from a group consisting of arsenic (As), gallium (Ga), aluminum (Al), indium (In), phosphorus (P), nitrogen (N), zinc (Zn), cadmium (Cd), and selenium (Se). In an embodiment of the present application, the first conductivity type of the first semiconductor layer **12** is different from the second conductivity type of the second semiconductor layer **16**. For example, the first semiconductor layer **12** can be an n-type semiconductor layer and the second semiconductor layer **16** can be a p-type semiconductor layer. The electrons provided from the n-type semiconductor layer and the holes provided from the p-type semiconductor layer combine in the first active layer **14** to emit the first light **14***a* under an external electrical current driving. The method for forming the first semiconductor light-emitting structure **10** is not particularly limited. The first semiconductor light-emitting structure **10** may be formed by a known epitaxy method such as metallic-organic chemical vapor deposition (MOCVD) method, a molecular beam epitaxy (MBE) method, a hydride vapor phase epitaxy (HVPE) method, sputtering or electrical plating. The material of the substrate **11** comprises germanium (Ge), gallium arsenide (GaAs), indium phosphide (InP), gallium phosphide (GaP), sapphire, silicon carbide (SiC), silicon (Si), lithium aluminate ($LiAlO_2$), zinc oxide (ZnO), gallium nitride (GaN), aluminum nitride (AlN). The substrate **11** can be used to support and/or grow the first semiconductor light-emitting structure **10**.

The material characteristic of the first thermal-sensitive layer **18** comprises transmittance which varies with the temperature change. The transmittance is proportional to the temperature. Specifically, the transmittance increases with increasing temperature. The material of the first thermal-sensitive layer **18** comprises organic compound or inorganic compound. The organic compound comprises esters or phenols, for example, crystal violet lactone, malachite green lactone, or cresol red, or metal organic complex compound, for example, copper complex compound, or liquid crystal. The inorganic compound comprises inorganic salts, such as vanadate or chromate, or inorganic crystals, such as mercuric iodide, silver iodide or vanadium oxide. When the organic compound or the inorganic compound is used as the material of the first thermal-sensitive layer **18**, the transmittance of the material varies with the temperature change of the light-emitting device **1**. As shown in FIG. **3**, the transmittance of the material increases with increasing temperature. The characteristic of the material is reversible, and the material can be reused. When the temperature gets back, the transmittance also gets back to a value before temperature increasing. With the transmittance dependence on temperature of the material of the first thermal-sensitive layer **18**, the color temperature variation of the light-emitting device **1** is improved.

As shown in FIG. **2** and FIG. **3**, with the characteristic of the low transmittance at low temperature, such as 25° C., of the first thermal-sensitive layer **18**, part of the first light **14***a* is blocked and less of the first light **14***a* can be transmitted through the first thermal-sensitive layer **18**. As shown in FIG. **3** and FIG. **4**, an electrical current is injected into the light-emitting device **1** through a first electrode **12***e* and a second electrode **16***e*, the temperature of the light-emitting device **1** increases from a lower temperature, such as 25° C., to a higher temperature, such as 85° C., the transmittance of the first thermal-sensitive layer **18** increases with increasing temperature, and more of the first light **14***a* can be transmitted through the first thermal-sensitive layer **18**. In accordance with an embodiment of the present application, with the characteristic that the transmittance of the first thermal-sensitive layer **18** is higher at high temperature, such as 85° C., than that at low temperature, such as 25° C., and with the characteristic that the light intensity of the light-emitting device **1** is lower at high temperature, such as 85° C., than that at low temperature, such as 25° C., the color temperature variation of the light-emitting device **1** is improved.

In accordance with another embodiment of the present application, the material characteristic of the first thermal-sensitive layer **18** of the light-emitting device **1** comprises refractive index. The first thermal-sensitive layer **18** comprises a first material having a first refractive index, such as liquid crystal, and a second material having a second refractive index, such as resin, wherein the first refractive index and the second refractive index vary with temperature changes.

When a junction temperature of the first active layer **14** is below 60° C., the first refractive index is different from the second refractive index; when a junction temperature of the first active layer **14** is above 60° C., a difference between the first refractive index and the second refractive index is substantially smaller than 10%. With the characteristic that the difference between the first refractive index and the second refractive index is larger than 10% at low temperature, such as 25° C., part of the first light **14***a* emitted from the light-emitting device **1** can be scattered and less of the first light **14***a* can be transmitted through the first thermal-sensitive layer **18**. When the electrical current is injected into the light-emitting device **1** through the first electrode **12***e* and the second electrode **16***e*, the temperature of the light-emitting device **1** increases from a lower temperature, such as 25° C., to a higher temperature, such as 85° C., wherein the difference between the first refractive index and the second refractive index is substantially smaller than 10%, and more of the first light **14***a* can be transmitted through the first thermal-sensitive layer **18**. In the embodiment of the present application, with the characteristic that the difference between the first refractive index and the second refractive index is substantially smaller than 10% at high temperature, such as 85° C., and with the characteristic that the light intensity of the light-emitting device **1** is lower at high temperature, such as 85° C., than that at low temperature, such as 25° C., the color temperature variation of the light-emitting device **1** is improved.

In accordance with another embodiment of the present application, the material of the first thermal-sensitive layer **18** of the light-emitting device **1** can be liquid crystal. The material characteristic comprises an arrangement of the liquid crystal molecules, wherein the arrangement of the liquid crystal molecules varies with the temperature change. The thermal-sensitive material, such as liquid crystal, comprises a stack structure, wherein major axes of the liquid crystal molecules in one layer of the stack structure are mutually parallel, but major axes of the liquid crystal molecules in adjacent one layer of the stack structure deviate from major axes of the liquid crystal molecules of the one layer of the stack structure. Overall, the liquid crystal molecules of the stack structure form a helical structure, and a periodic pitch is formed between layer and layer. The temperature change changes the pitch, different pitches reflect different wavelengths. With the characteristic described above, more of the first light **14***a* emitted from the light-emitting device **1** can be scattered at a lower temperature, such as 25° C., and more of the first light **14***a* can be transmitted through the first thermal-sensitive layer **18** at a higher temperature, such as 85° C., and with the characteristic that the light intensity of the light-emitting device **1** is lower at high temperature, such as 85° C., than that at low temperature, such as 25° C., the color temperature variation of the light-emitting device **1** is improved.

As shown in FIG. **5**, the first thermal-sensitive layer **18** of the light-emitting device **1** can be formed on at least one surface **10***s* of the first semiconductor light-emitting structure **10**, and preferably, the first thermal-sensitive layer **18** contacts with at least one surface **10***s* of the first semiconductor light-emitting structure **10**.

FIG. **6** illustrates a cross-sectional diagram of a light-emitting device **2** in accordance with a second embodiment of the present application. The light-emitting device **2** comprises a substrate **21**; a first semiconductor light-emitting structure **20** formed on the substrate **21**, wherein the first semiconductor light-emitting structure **20** comprises a first semiconductor layer **22** having a first conductivity type, a second semiconductor layer **26** having a second conductivity type and a first active layer **24** formed between the first semiconductor layer **22** and the second semiconductor layer **26**, wherein the first active layer **24** is capable of emitting a first light **24***a* having a first dominant wavelength; a light-pervious layer **23** covering the first semiconductor light-emitting structure **20**; and a first thermal-sensitive layer **28** formed on a path of the first light **24***a*, wherein the first thermal-sensitive layer **28** comprises a material characteristic which varies with the temperature change.

As shown in FIG. **6**, the light-pervious layer **23** comprises a transparent material **231**, and the transparent material **231** can be organic material or inorganic material. The organic material comprises epoxy, polymethylmethacrylate (PMMA), or silicone. The inorganic material comprises glass. The manufacturing method of the light-pervious layer **23** is not particularly limited, in addition to potting, the light-pervious layer **23** can also be formed by low-pressure transfer molding or adhesion. The first light **24***a* emitted from the first semiconductor light-emitting structure **20** can be transmitted to the environment through the light-pervious layer **23**. The light-pervious layer **23** also provides electrical insulation and heat resistance. The light-pervious layer **23** protects the first semiconductor light-emitting structure **20** from being directly exposed to the environment.

The material of the first semiconductor light-emitting structure **20** comprises an element selected from a group consisting of arsenic (As), gallium (Ga), aluminum (Al), indium (In), phosphorus (P), nitrogen (N), zinc (Zn), cadmium (Cd) and selenium (Se). In an embodiment of the present application, the first conductivity type of the first semiconductor layer **22** is different from the second conductivity type of the second semiconductor layer **26**. For example, the first semiconductor layer **22** can be an n-type semiconductor layer and the second semiconductor layer **26** can be a p-type semiconductor layer. The electrons provided from the n-type semiconductor layer and the holes provided from the p-type semiconductor layer combine in the first active layer **24** to emit the first light **24***a* under an external electrical current driving. The manufacturing method of the first semiconductor light-emitting structure **20** is not particularly limited, the first semiconductor light-emitting structure **20** may be formed by a known epitaxy method such as metallic-organic chemical vapor deposition (MOCVD) method, a molecular beam epitaxy (MBE) method, a hydride vapor phase epitaxy (HVPE) method, sputtering, or electrical plating.

The first semiconductor light-emitting structure **20** can be formed on the substrate **21** by glue bonding or metal bonding. The substrate **21** comprises conductive material, such as metal. The first semiconductor light-emitting structure **20** further comprises a first electrode **22***e* and a second electrode **26***e*, wherein a position of the first electrode **22***e* or the second electrode **26***e* is not particularly limited. The first electrode **22***e* and the second electrode **26***e* can be formed on a same side of the first semiconductor light-emitting structure **20** to form a horizontal structure as shown in FIG. **6**. The first electrode **22***e* and the second electrode **26***e* also can be formed on opposite sides of the first semiconductor light-emitting structure **20** to form a vertical structure (not shown). As shown in FIG. **6**, a cavity **232** formed between the first electrode **22***e* and the second electrode **26***e* comprises insulated glue material or air when the first electrode **22***e* and the second electrode **26***e* are formed on the same side of the first semiconductor light-emitting structure **20**.

The material characteristic of the first thermal-sensitive layer **28** comprises transmittance which varies with the temperature change. The transmittance is proportional to the temperature. Specifically, the transmittance increases when the temperature is raised. The material of the first thermal-sensitive layer **28** comprises organic compound or inorganic compound. The organic compound comprises esters or phenols, for example, crystal violet lactone, malachite green lactone, or cresol red, or metal organic complex compound, for example, copper complex compound, or liquid crystal. The inorganic compounds comprise inorganic salts, such as vanadate or chromate, or inorganic crystals, such as mercuric iodide, silver iodide or vanadium oxide. When the organic compound or the inorganic compound is used as the material of the first thermal-sensitive layer **28**, the transmittance of the material varies with the temperature change of the light-emitting device **2**. As shown in FIG. **3**, the transmittance of the material increases with increasing temperature. The material is reversible and can be reused. When the temperature gets back, the transmittance also gets back to a value before temperature increasing. With the transmittance dependence on temperature of the thermal-sensitive material of the first thermal-sensitive layer **28**, the color temperature variation of the light-emitting device **2** is improved.

As shown in FIG. **6**, with the characteristic of the low transmittance at low temperature, such as 25° C., of the first thermal-sensitive layer **28**, part of the first light **24***a* is blocked by the first thermal-sensitive layer **28** and part of the first light **24***a* is transmitted through the first thermal-sensitive layer **28**. An electrical current is injected into the first electrode **22***e* and the second electrode **26***e* of the light-emitting device **2** through the substrate **21**. When the electrical current is injected into the light-emitting device **2**, the temperature of the light-emitting device **2** increases from a low temperature, such as 25° C., to a high temperature, such as 85° C., the transmittance of the first thermal-sensitive layer **28** increases with increasing temperature, and more of the first light **24***a* can be transmitted through the first thermal-sensitive layer **28**. In accordance with an embodiment of the present application, with the characteristic that the transmittance of the first thermal-sensitive layer **28** is higher at high temperature, such as 85° C., than that at low temperature, such as 25° C., and with the characteristic that the light intensity of the light-emitting device **2** is lower at high temperature, such as 85° C., than that at low temperature, such as 25° C., the color temperature variation of the light-emitting device **2** is improved.

In accordance with another embodiment of the present application, the material characteristic of the first thermal-sensitive layer **28** of the light-emitting device **2** comprises refractive index. The first thermal-sensitive layer **28** comprises a first material having a first refractive index, such as liquid crystal, and a second material having a second refractive index, such as resin, wherein the first refractive index and the second refractive index vary with temperature changes. When a junction temperature of the first active layer **24** is below 60° C., the first refractive index is different from the second refractive index; when a junction temperature of the first active layer **24** is above 60° C., a difference between the first refractive index and the second refractive index is substantially smaller than 10%.

In accordance with another embodiment of the present application, the material of the first thermal-sensitive layer **28** of the light-emitting device **2** can be liquid crystal. The material characteristic comprises an arrangement of the liquid crystal molecules. With the characteristic of the liquid crystal, more of the first light **24***a* emitted from the light-emitting device **2** can be scattered at low temperature, such as 25° C., and more of the first light **24***a* can be transmitted through the first thermal-sensitive layer **28** at high temperature, such as 85° C., and with the characteristic that the light intensity of the light-emitting device **2** is lower at high temperature, such as 85° C., than that at low temperature, such as 25° C., the color temperature variation of the light-emitting device **2** is improved.

As shown in FIG. **7**, the first thermal-sensitive layer **28** of the light-emitting device **2** can be formed on at least one surface **20***s* of the first semiconductor light-emitting structure **20**, and preferably, the first thermal-sensitive layer **28** contacts with at least one surface **20***s* of the first semiconductor light-emitting structure **20**.

The light-emitting device **2** further comprises a wavelength converting material **25** formed on a path of the first light **24***a*, wherein the wavelength converting material **25** comprising phosphor is capable of absorbing the first light **24***a* emitted from the first active layer **24** and emitting a third light **24***b* having a third dominant wavelength. FIG. **8** illustrates an example that the wavelength converting material **25** can be mixed with the transparent material **231** of the light-pervious layer **23**.

As shown in FIG. **9**, the first thermal-sensitive layer **28** of the light-emitting device **2** can be formed on the surface **20***s* of the first semiconductor light-emitting structure **20** and covers at least one side surface **20***t* of the first semiconductor light-emitting structure **20**. In another example, the first thermal-sensitive layer **28** contacts with the side surface **20***t*, wherein the wavelength converting material **25** can be added into the first thermal-sensitive layer **28**.

As shown in FIG. **10**, the first thermal-sensitive layer **28** of the light-emitting device **2** can be formed on the surface **20***s* of the first semiconductor light-emitting structure **20**, and covers at least one side surface **20***t* of the first semiconductor light-emitting structure **20**. In another example, the first thermal-sensitive layer **28** contacts with the side surface **20***t*, wherein the wavelength converting material **25** can be formed on at least one surface **28***s* of the first thermal-sensitive layer **28** through an adhesion material, such as resin.

As shown in FIG. **11**, the first thermal-sensitive layer **28** of the light-emitting device **2** can be formed on the surface **20***s* of the first semiconductor light-emitting structure **20**, and covers at least one side surface **20***t* of the first semiconductor light-emitting structure **20**. The wavelength converting material **25** can be formed on the surface **20***s* and the side surface **20***t* of the first semiconductor light-emitting structure **20** through an adhesion material, such as resin. In another example, the wavelength converting material **25** can contact with the surface **20***s* and the side surface **20***t*.

As shown in FIG. **12**, the material of the first thermal-sensitive layer **28** of the light-emitting device **2** and the wavelength converting material **25** can be added into the transparent material **231** of the light-pervious layer **23**.

As shown in FIG. **13**, the first thermal-sensitive layer **28** of the light-emitting device **2** can be formed on the surface **23***s* of the light-pervious layer **23**, and preferably, the first thermal-sensitive layer **28** contacts with the surface **23***s* of the light-pervious layer **23**.

As shown in FIG. **14**, the first thermal-sensitive layer **28** of the light-emitting device **2** can be formed on the surface **23***s* of the light-pervious layer **23**, and preferably, the first thermal-sensitive layer **28** contacts with the surface **23***s* of the light-pervious layer **23**, and the wavelength converting material **25** can be added into the transparent material **231** of the light-pervious layer **23**.

As shown in FIG. **15**, the first thermal-sensitive layer **28** of the light-emitting device **2** can be formed on the surface **23***s* of the light-pervious layer **23**. In another example, the first thermal-sensitive layer **28** contacts with the surface **23***s* of the light-pervious layer **23**. The wavelength converting material

25 can be formed on a surface 25s of the first thermal-sensitive layer 28 through an adhesion material, such as resin, wherein the surface 25s is more close to the first semiconductor light-emitting structure 20.

As shown in FIG. 16, the first thermal-sensitive layer 28 of the light-emitting device 2 can be formed on the surface 23s of the light-pervious layer 23. In another example, the first thermal-sensitive layer 28 contacts with the surface 23s of the light-pervious layer 23. The wavelength converting material 25 can be formed on a surface 25s of the first thermal-sensitive layer 28 through an adhesion material, such as resin, wherein the surface 25s is away from the first semiconductor light-emitting structure 20.

FIG. 17 illustrates a cross-sectional diagram of a light-emitting device 3 in accordance with a third embodiment of the present application. The light-emitting device 3 comprises a substrate 31; a first semiconductor light-emitting structure 30 formed on the substrate 31, wherein the first semiconductor light-emitting structure 30 comprises a first semiconductor layer 32 having a first conductivity type, a second semiconductor layer 36 having a second conductivity type and a first active layer 34 formed between the first semiconductor layer 32 and the second semiconductor layer 36, wherein the first active layer 34 is capable of emitting a first light 34a having a first dominant wavelength; a light-pervious layer 33 covering the first semiconductor light-emitting structure 30; and a first thermal-sensitive layer 38 formed on a path of the first light 34a, wherein the first thermal-sensitive layer 38 comprises a material characteristic which varies with the temperature change.

As shown in FIG. 17, the first thermal-sensitive layer 38 of the light-emitting device 3 can be formed on at least one surface 30s of the first semiconductor light-emitting structure 30, and preferably, the first thermal-sensitive layer 38 contacts with the surface 30s of the first semiconductor light-emitting structure 30.

The material of the light-pervious layer 33 comprises organic material or inorganic material. The organic material comprises epoxy, polymethylmethacrylate (PMMA), or silicone. The inorganic material comprises glass. The manufacturing method of the light-pervious layer 33 is not particularly limited, in addition to potting, the light-pervious layer 33 can also be formed by low-pressure transfer molding or adhesion. The first light 34a emitted from the first semiconductor light-emitting structure 30 can be transmitted to the environment through the light-pervious layer 33. The light-pervious layer 33 also provides electrical insulation and heat resistance. The light-pervious layer 33 protects the first semiconductor light-emitting structure 30 from being directly exposed to the environment.

The material of the first semiconductor light-emitting structure 30 comprises an element selected from a group consisting of arsenic (As), gallium (Ga), aluminum (Al), indium (In), phosphorus (P), nitrogen (N), zinc (Zn), cadmium (Cd) and selenium (Se). In an embodiment of the present application, the first conductivity type of the first semiconductor layer 32 is different from the second conductivity type of the second semiconductor layer 36. For example, the first semiconductor layer 32 can be an n-type semiconductor layer and the second semiconductor layer 36 can be a p-type semiconductor layer. The electrons provided from the n-type semiconductor layer and the holes provided from the p-type semiconductor layer combine in the first active layer 34 to emit the first light 34a under an external electrical current driving. The manufacturing method of the first semiconductor light-emitting structure 30 is not particularly limited, the first semiconductor light-emitting structure 30 may be formed by a known epitaxy method such as metallic-organic chemical vapor deposition (MOCVD) method, a molecular beam epitaxy (MBE) method, a hydride vapor phase epitaxy (HVPE) method, sputtering or electrical plating.

The first semiconductor light-emitting structure 30 can be formed on the substrate 31 by glue bonding or metal bonding. The substrate 31 comprises conductive material, such as metal. The first semiconductor light-emitting structure 30 further comprises a first electrode 32e and a second electrode 36e, wherein a position of the first electrode 32e or the second electrode 36e is not particularly limited. The first electrode 32e and the second electrode 36e can be formed on a same side of the first semiconductor light-emitting structure 30 to form a horizontal structure as shown in FIG. 17. The first electrode 32e and the second electrode 36e also can be formed on opposite sides of the first semiconductor light-emitting structure 30 to form a vertical structure (not shown). As shown in FIG. 17, a cavity 332 formed between the first electrode 32e and the second electrode 36e comprises insulated glue material or air when the first electrode 32e and the second electrode 36e are formed on the same side of the first semiconductor light-emitting structure 30.

The material characteristic of the first thermal-sensitive layer 38 comprises transmittance which varies with the temperature change. The transmittance is proportional to the temperature. Specifically, the transmittance increases when the temperature is raised. The material of the first thermal-sensitive layer 38 comprises organic compound or inorganic compound. The organic compound comprises esters or phenols, for example, crystal violet lactone, malachite green lactone, or cresol red, or metal organic complex compound, for example, copper complex compound, or liquid crystal. The inorganic compounds comprise inorganic salts, such as vanadate or chromate, or inorganic crystals, such as mercuric iodide, silver iodide or vanadium oxide. When the organic compound or the inorganic compound is used as the material of the first thermal-sensitive layer 38, the transmittance of the material varies with the temperature change of the light-emitting device 3. As shown in FIG. 3, the transmittance of the material increases with increasing temperature. The material is reversible and can be reused. When the temperature gets back, the transmittance also gets back to a value before temperature increasing. With the transmittance dependence on temperature of the thermal-sensitive material of the first thermal-sensitive layer 38, the color temperature variation of the light-emitting device 3 is improved.

In accordance with another embodiment of the present application, the material of the first thermal-sensitive layer 38 of the light-emitting device 3 can be liquid crystal. The material characteristic comprises an arrangement of the liquid crystal molecules.

As shown in FIG. 17, the light-emitting device 3 of the third embodiment of the present application further comprises at least a second semiconductor light-emitting structure 40 formed on the substrate 31, wherein the second semiconductor light-emitting structure 40 is adjacent to the first semiconductor light-emitting structure 30 and covered by the light-pervious layer 33 with the first semiconductor light-emitting structure 30. The second semiconductor light-emitting structure 40 comprises a third semiconductor layer 42 having a first conductivity type, a fourth semiconductor layer 46 having a second conductivity type and a second active layer 44 formed between the third semiconductor layer 42 and the fourth semiconductor layer 46, wherein the second active layer 44 is capable of emitting a second light 44a having a second dominant wavelength, wherein the second dominant wavelength of the second light **44***a* is different from the first dominant wavelength of the first light **34***a*.

The material of the first semiconductor light-emitting structure **40** comprises an element selected from a group consisting of arsenic (As), gallium (Ga), aluminum (Al), indium (In), phosphorus (P), nitrogen (N), zinc (Zn), cadmium (Cd) and selenium (Se). In an embodiment of the present application, the first conductivity type of the first semiconductor layer **42** is different from the second conductivity type of the second semiconductor layer **46**. For example, the first semiconductor layer **42** can be an n-type semiconductor layer and the second semiconductor layer **46** can be a p-type semiconductor layer. The electrons provided from the n-type semiconductor layer and the holes provided from the p-type semiconductor layer combine in the first active layer **44** to emit the first light **44***a* under an external electrical current driving. The manufacturing method of the first semiconductor light-emitting structure **40** is not particularly limited, the first semiconductor light-emitting structure **40** may be formed by a known epitaxy method such as metallic-organic chemical vapor deposition (MOCVD) method, a molecular beam epitaxy (MBE) method, a hydride vapor phase epitaxy (HVPE) method, sputtering or electrical plating.

The second semiconductor light-emitting structure **40** can be formed on the substrate **31** by glue bonding or metal bonding. The second semiconductor light-emitting structure **40** further comprises a third electrode **42***e* and a fourth electrode **46***e*, wherein a position of the third electrode **42***e* or the fourth electrode **46***e* is not particularly limited. The third electrode **42***e* and the fourth electrode **46***e* can be formed on a same side of the second semiconductor light-emitting structure **40** to form a horizontal structure as shown in FIG. **17**. The third electrode **42***e* and the fourth electrode **46***e* also can be formed on opposite sides of the second semiconductor light-emitting structure **40** to form a vertical structure (not shown). As shown in FIG. **17**, a cavity **432** formed between the third electrode **42***e* and the fourth electrode **46***e* comprises insulated glue material or air when the third electrode **42***e* and the fourth electrode **46***e* are formed on the same side of the second semiconductor light-emitting structure **40**.

As shown in FIG. **17**, the first light **34***a* of the first semiconductor light-emitting structure **30** can be mixed with the second light **44***a* of the second semiconductor light-emitting structure **40** to emit a fourth light **34***b* having a fourth dominant wavelength, wherein the first light **34***a* can be a red light, the second light **44***a* can be a blue light, the fourth light **34***b* can be a white light.

As shown in FIG. **18**, the light-emitting device **3** of the third embodiment of the present application further comprises a second thermal-sensitive layer **48** formed on at least one surface **40***s* of the second semiconductor light-emitting structure **40**, and preferably, contacts with at least one surface **40***s* of the second semiconductor light-emitting structure **40**, wherein the second thermal-sensitive layer **48** comprises a material different from that of the first thermal-sensitive layer **38**. In one example of the embodiment, a thickness of the second thermal-sensitive layer **48** is different from that of the first thermal-sensitive layer **38**. The first semiconductor light-emitting structure **30** and the second semiconductor light-emitting structure **40** have a different degree of photo decay on temperature, different materials or different thickness of the first thermal-sensitive layer **38** and the second thermal-sensitive layer **48** can be used to adjust the light intensity of the first semiconductor light emitting structure **30** and the second semiconductor light-emitting structure **40** to improve the variation of the color temperature of the light-emitting device **3**.

In the embodiment, an electrical current can be injected into the first electrode **32***e* and the second electrode **36***e* of the first semiconductor light-emitting structure **30** and the third electrode **42***e* and the fourth electrode **46***e* of the second semiconductor light-emitting structure **40** through the substrate **31** of the light-emitting device **3**. The first semiconductor light-emitting structure **30** and the second semiconductor light-emitting structure **40** have a different degree of photo decay on temperature, when a temperature of the light-emitting device **3** increases from a room temperature, such as 25° C., to a temperature higher than the room temperature, such as 85° C., the photo decay of the light intensity of the first light **34***a*, for example, the red light, is larger than the photo decay of the light intensity of the second light **44***a*, for example, the blue light. The first semiconductor light-emitting structure **30** and the second semiconductor light-emitting structure **40** have a different degree of photo decay on temperature, the first thermal-sensitive layer **38** and the second thermal-sensitive layer **48** can be used to reduce the variation of the color temperature of the light-emitting device **3** between room temperature and thermal equilibrium.

As shown in FIG. **19**, the light-emitting device **3** further comprises a wavelength converting material **45** formed on a path of the second light **44***a*. In an embodiment of the present application, the wavelength converting material **45** can be formed on at least one surface **40***s* of the second semiconductor light-emitting structure **40** through an adhesion material, such as resin. Preferably, the wavelength converting material **45** contacts with at least one surface **40***s* of the second semiconductor light-emitting structure **40**. The wavelength converting material **45**, for example, phosphor, is capable of absorbing the second light **44***a* emitted from the second active layer **44** and emitting a third light **44***b* having a third dominant wavelength. The first light **34***a* of the first semiconductor light-emitting structure **30** can be mixed with the third light **44***b* of the second semiconductor light-emitting structure **40** to emit a fourth light **34***d* having a fourth dominant wavelength, wherein the first light **34***a* can be a red light, the second light **44***b* can be a white light, the fourth light **34***d* can be a white light.

FIG. **20** illustrates a diagram of light intensity dependence on temperature of a light-emitting device of the present application. As shown in FIG. **20**, when an electrical current is injected into the light-emitting device, a temperature of the light-emitting device increases from an original room temperature, such as 25° C., to a higher temperature, such as 85° C. or above, the light intensity of the light-emitting device at 25° C. is 50~85% of that of the red chip shown in FIG. **1**A. The attenuation rate of the light intensity versus temperature of the light-emitting device of the present application is approximately −0.05~0.4%. FIG. **21** illustrates a diagram of emission wavelength dependence on temperature of a light-emitting device of the present application. As shown in FIG. **21**, when the external electrical current is injected into the light-emitting device, the temperature of the light-emitting device increases from an original temperature to a higher temperature, such as from 25° C. to 85° C. or above. When the temperature increases from 25° C. to 100° C., the emission wavelength of the light-emitting device increases 2~3 nm.

The principle and the efficiency of the present application illustrated by the embodiments above are not the limitation of the application. Any person having ordinary skill in the art can modify or change the aforementioned embodiments. Therefore, the protection range of the rights in the application will be listed as the following claims.

What is claimed is:

1. A light-emitting device, comprising:

a substrate;

a first semiconductor light-emitting structure formed on the substrate, wherein the first semiconductor light-emitting structure comprises:

a first semiconductor layer having a first conductivity type;

a second semiconductor layer having a second conductivity type; and

a first active layer formed between the first semiconductor layer and the second semiconductor layer, wherein the first active layer is capable of emitting a first light having a first dominant wavelength; and

a first thermal-sensitive layer formed on a path of the first light, wherein the first thermal-sensitive layer comprises a material characteristic which varies within a temperature range and a first intensity difference of the first light after being transmitted through the first thermal-sensitive layer within the temperature range is smaller than a second intensity difference of the first light before being transmitted into the first thermal-sensitive layer within the temperature range.

2. The light-emitting device of claim **1**, wherein the first thermal-sensitive layer contacts with one surface of the first semiconductor light-emitting structure.

3. The light-emitting device of claim **1**, further comprising a light-pervious layer covering the first semiconductor light-emitting structure.

4. The light-emitting device of claim **3**, wherein the first thermal-sensitive layer is formed between the light-pervious layer and the first semiconductor light-emitting structure.

5. The light-emitting device of claim **1**, further comprising a wavelength converting material formed on the path of the first light.

6. The light-emitting device of claim **5**, wherein the wavelength converting material is formed in the light-pervious layer.

7. The light-emitting device of claim **5**, further comprising a second semiconductor light-emitting structure formed on the substrate, adjacent to the first semiconductor light-emitting structure and covered by the light-pervious layer, wherein the second semiconductor light-emitting structure comprises:

a third semiconductor layer having the first conductivity type;

a fourth semiconductor layer having the second conductivity type; and

a second active layer formed between the third semiconductor layer and the fourth semiconductor layer, wherein the second active layer is capable of emitting a second light having a second dominant wavelength.

8. The light-emitting device of claim **7**, wherein the wavelength converting material is formed on a surface of the first semiconductor light-emitting structure.

9. The light-emitting device of claim **7**, further comprising a second thermal-sensitive layer formed on a surface of the second semiconductor light-emitting structure.

10. The light-emitting device of claim **9**, wherein a material and/or a thickness of the second thermal-sensitive layer is different from that of the first thermal-sensitive layer.

11. The light-emitting device of claim **3**, wherein the first thermal-sensitive layer is formed on the light-pervious layer.

12. The light-emitting device of claim **3**, further comprising a wavelength converting material formed on the light-pervious layer.

13. The light-emitting device of claim **1**, wherein the material characteristic includes at least one of transmittance and refractive index.

14. The light-emitting device of claim **13**, wherein the transmittance with respect to the first light is directly proportional to the temperature in the temperature range.

15. The light-emitting device of claim **1**, wherein the thermal-sensitive layer comprises organic compound, inorganic compound, or liquid crystal.

16. The light-emitting device of claim **13**, wherein the thermal-sensitive layer comprises a first material having a first refractive index and a second material having a second refractive index.

17. The light-emitting device of claim **16**, wherein a difference between the first refractive index and the second refractive index is substantially smaller than 10% when a junction temperature of the active layer is above 60° C.

18. The light-emitting device of claim **17**, wherein the first material comprises liquid crystal and the second material comprises resin.

19. The light-emitting device of claim **1**, wherein the first light comprises red light.

20. The light-emitting device of claim **1**, wherein the temperature range comprises a first temperature and a second temperature higher than the first temperature, and an intensity of the first light attenuates from the first temperature to the second temperature.

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